

Evaporation Research — A Review and Interpretation

By C.M. Burt, A.J. Mutziger, R.G. Allen, and T.A. Howell

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1.1 Background

Evapotranspiration (ET) represents the major consumptive use of irrigation water and rainfall on agricultural land. There has been considerable research to define ET for various crops and to understand the relationship between ET and crop yield. Because transpiration (T) is the portion of ET that flows through the plant system, it is the main component of ET that impacts the ET – yield relationship. Nevertheless, the evaporation (E) component within and outside the crop growing season can be a significant component of the total ET. Given the increased competition for water in the state, it is important to search for new ways to conserve water and/or to use it more efficiently. This paper examines the factors that affect the E component, and the relative percentage of E in the overall ET balance.

Most of the literature reviewed provided information in a format that did not lend itself to direct comparison with other literature results. Therefore, within this paper various data have been re-arranged and organized so that results can be compared. However, because of the sheer volume of work required, the authors have not attempted to re-create figures and tables found in the literature; these were simply scanned into the document.

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1.1.1 What Falls under "Evaporation"

Evaporation in a soil-plant-atmosphere system occurs from each of the system components. Evaporation from the *soil* is effected by soil water content, type, and tilth, the presence or absence of surface mulches, and the environmental conditions being imposed on the soil. Evaporation from the *plant surfaces* is effected by the plant canopy water storage capacity, the length of time that rain or irrigation water is impacting the plants, and the environmental conditions imposed on the plants. Evaporation from the atmosphere (*sprinkler droplet evaporation*) is associated with sprinkler irrigation methods and is the amount of applied water that does not reach the soil-plant system, but does not include drift losses. It is affected by droplet size, relative humidity, angle and distance of droplet travel, and water temperature. Transpiration (T) is a specific form of evaporation in which water from plant tissue is vaporized and removed to the atmosphere primarily through the plant stomata. The combined water that is transferred to the atmosphere through evaporation (E) and transpiration (T) processes is known as evapotranspiration.

1.1.2 Evaporation Equations

In general, evaporation has been estimated in research using four approaches:

1. Water balance method
2. Energy balance method
3. Coupled water and energy balance methods
4. Semi-empirical and empirical methods

1.1.2.1 *Water Balance Method*

The general water balance equation for determining evaporative loss from soil, foliage, and sprinkler spray and transpiration is:

$$E + T = P + I + \Delta S - D - R \quad (1)$$

where E is evaporation, T is transpiration, P is precipitation, I is irrigation, ΔS is change in soil water storage for the medium of interest, and D and R are drainage or runoff losses for the medium of interest. The units are water depth over the evaluated time frame (e.g. mm d⁻¹).

In the soil medium, E can be separated from evapotranspiration (ET) by either measuring E with micro-lysimeters, by measuring T with stem flow gauges, or by having no plants in the system.

1.1.2.2 *Energy Balance Method*

The general surface energy balance equation is given by:

$$LE = ET = R_N - G - H \quad (2)$$

where LE is the outgoing latent heat flux from evaporation and transpiration, R_N is the incoming net solar radiation, G is the soil heat flux, and H is the sensible heat flux above the canopy. The units for these terms are commonly watts m^{-2} (1mm of ET $d^{-1} = 28.36$ watts m^{-2}). The equation components can be measured remotely with sensing technologies or on the ground with Bowen Ratio or Eddy Correlation equipment. Considerable work is being done with remote sensing to enable accurate estimation of regional water losses; that work is in the development stages and cannot provide a detailed breakdown of evaporation and transpiration.

A variety of radiation-temperature based energy balance models (Jensen and Haise, 1963; Priestley and Taylor, 1972; Jensen et al., 1990) have been developed. But over the past 20 years the emphasis has been on the Penman method, modified Penman methods, and the Penman-Monteith methods. These utilize the weather components of solar radiation, relative humidity, wind run, and air temperature to estimate a reference crop ET. When combined with a crop coefficient, the reference crop ET can be used to estimate crop ET. The most recent version of such methods is referred to in this paper as the “FAO - 56 Method”, which is the procedure described by Allen et al. (1998).

One of the mass transfer models evaluated, Cupid-DPEVAP (Thompson et al., 1993a, 1993b, 1997), determines evaporation from wet foliage with an energy balance equation that uses leaf storage capacity and the depth of the intercepted water. The DPEVAP model and a similar model by Kincaid and Longley (1989) combine heat transfer and diffusion theory in an energy balance to estimate sprinkler evaporation.

1.1.2.3 Coupled Water and Energy Balance Methods

Coupled water and energy balance methods tend to be complex and require many field-measured and sensitive parameters, making them impractical for large scale estimation studies.

1.1.2.4 Semi-empirical and Empirical Methods

These methods apply only to bare soil evaporation. Several semi-empirical and empirical relationships for E have been developed, but they are very site specific (e.g., non-transferable). One such method presented in Stroonsnijder (1987), Gallardo et al. (1996), and Snyder et al. (2000) is a variation on the classic two-stage evaporation model presented by Ritchie (1972). In both methods, Stage 1 evaporation from the soil is limited only by the energy input. For Stage 2, Ritchie (1972) identified a semi-empirical evaporation equation that was a function of the square root of time. The more recent papers found a good semi-empirical relationship between cumulative bare soil evaporation and cumulative reference evapotranspiration.

1.2 Soil Evaporation

1.2.1 FAO-56 Method and Modifications

1.2.1.1 *Single and Dual Crop Coefficient in FAO - 56*

The Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage paper 56 (Allen et al., 1998) provides a good summary of how crop coefficients in conjunction with reference ET measurements are used to determine ET for the crop (ET_c) or estimate the partitioning of ET into E and T. In general, the single crop coefficient (K_c) is used to define ET_c :

$$ET_c = K_c ET_o \quad (3)$$

where ET_o is the ET from a pristine reference grass as defined in the FAO - 56 (Allen et al, 1998).

The K_c term in equation 3 can be replaced as a dual crop coefficient to partition E and T:

$$K_c = K_s K_{cb} + K_e \quad (4)$$

where K_s is the reduction coefficient for crop stress, K_{cb} is the basal crop coefficient, or the ratio of ET_c to ET_o for dry surface soil conditions in which the water content in the underlying soil does not limit the full plant transpiration needs, and K_e is a soil water evaporation coefficient. In general, transpiration is obtained by multiplying the product of K_s and K_{cb} by ET_o and evaporation is computed by multiplying K_e by ET_o . Details such as upper limits to the coefficients are discussed in Allen et al (1998).

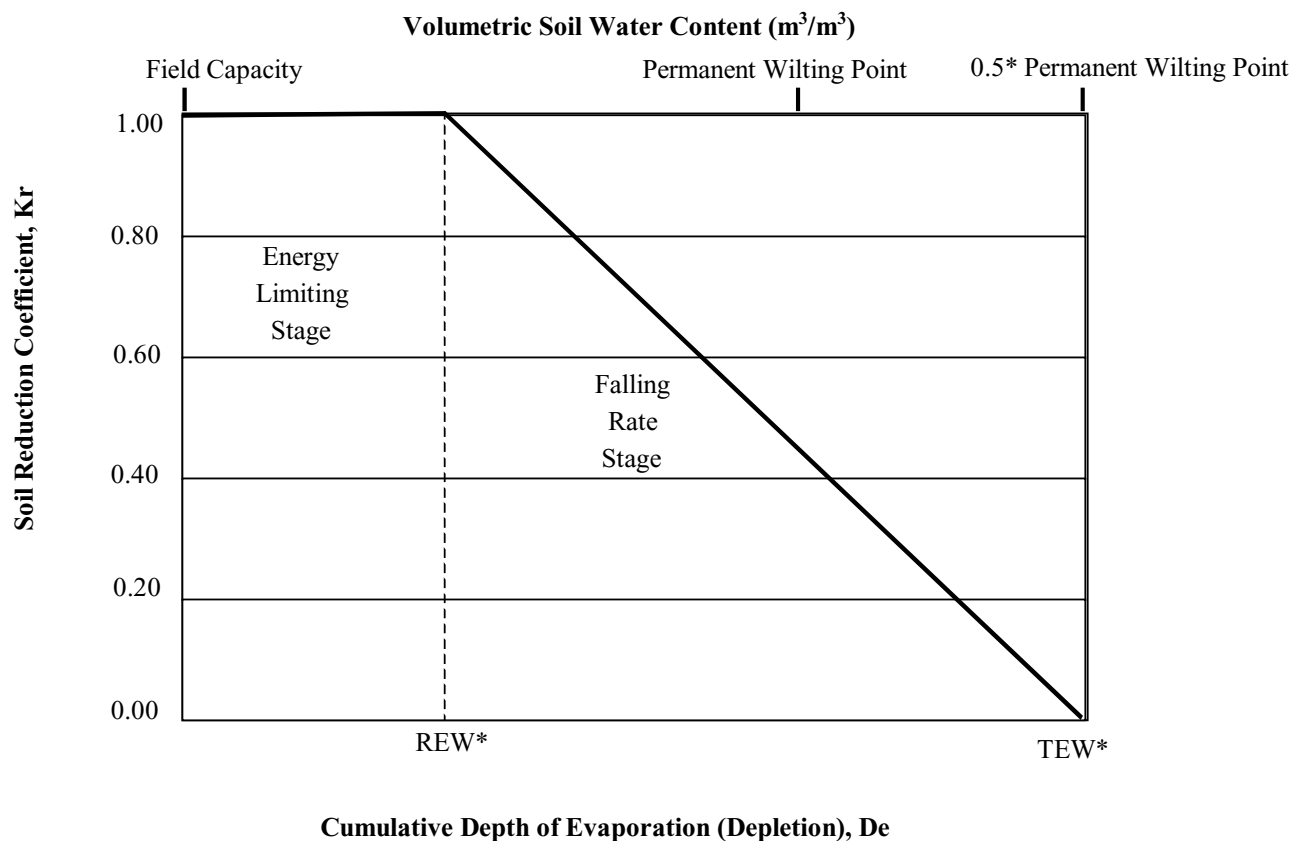
1.2.1.2 *Comparison of FAO - 56 Kr Against Measured Kr of Three Soil Types from One*

Source

FAO - 56 gives the following description of the evaporation reduction coefficient, K_r :

Evaporation from the exposed soil can be assumed to take place in two stages: an energy limiting stage, and a falling rate stage. When the soil surface is wet, K_r is 1. When the water content in the upper soil becomes limiting, K_r decreases and becomes zero when the total amount of water that can be evaporated from the topsoil is depleted.

Stage 1 is assumed to exist until the soil surface color lightens due to the loss of moisture. Figure 3-1 graphically presents a general case of the two stage relationship. It illustrates Figure 38 of Allen et al (1998).



*REW - Readily Evaporable Water

*TEW - Total Evaporable Water

Figure 3-1. Cumulative evaporation depth (De) or volumetric soil water content versus the FAO - 56 soil evaporation reduction coefficient (K_r) (Allen et al, 1998). Note that FAO - 56 assumes that the total evaporable water (TEW) has been depleted when the volumetric soil water content is reduced to half of the permanent wilting point water content for the soil.

Chanzy and Bruckler (1993) presented the measured K_r relationship for three bare soils in Avignon, France (Figure 3-2). They used soil samples to compute the volumetric soil water content in the first 0.05 m of soil and the amount of soil evaporation (E) that was the result of the potential soil evaporation (E_p) for a given day as defined by Penman (1948). The evaporation reduction coefficient is then given by $K_r = E/E_p$.

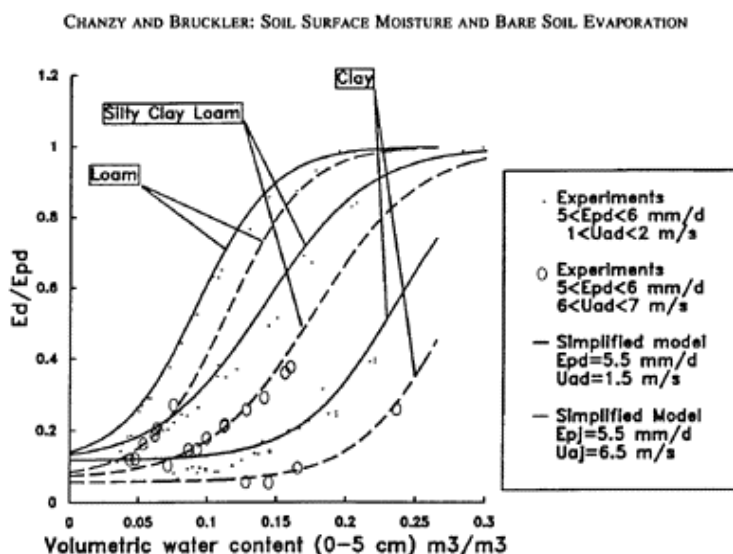


Figure 3-2. Ratio of daily bare soil evaporation (E_d) to daily potential soil evaporation (E_{pd}) as related to the volumetric water content in the first 5 cm of soil for 3 different soil types, 1 range of E_{pd} , and for 2 ranges of average daily wind speed (U_{ad}). Chanzy and Bruckler (1993) *(Note: Since higher wind speed results in higher evaporation, it appears that the legend definitions for the dot and circle symbols of this figure [Figure 8 from Chanzy and Bruckler, 1993] need to be interchanged).*

Since the specific loam, silty clay loam, and clay properties for the Avignon soils presented in Chanzy and Bruckler (1993) were not known, we used soil property ranges given in FAO - 56 (Table 3-1) to define average FAO - 56 Kr relationship for these soil types (Table 3-2).

Table 3-1. Range of FAO - 56 parameters for defining the evaporation reduction coefficient (Kr) relationship for loam, silty clay loam, and clay soils (Allen et al, 1998).

	FAO - 56 θ_{FC}^A Range (m^3 Soil Water / m^3 Soil)	FAO - 56 θ_{WP}^B Range (m^3/m^3)	FAO - 56 Range of Plant Available Water, $\theta_{FC} - \theta_{WP}$ (m^3/m^3)	FAO - 56 Stage 1 REW ^C Range (mm)	FAO - 56 Stage 1 & 2 TEW ^D Range ($Ze = 0.1m$) ^E (mm)
Loam	0.20 - 0.30	0.07 - 0.17	0.13 - 0.18	8-10	16-22
Silty Clay Loam	0.30 - 0.37	0.17 - 0.24	0.13 - 0.18	8-11	22-27
Clay	0.32 - 0.40	0.20 - 0.24	0.12 - 0.20	8-12	22-29

^A θ_{FC} is the volumetric water content of the soil at field capacity

^B θ_{WP} is the volumetric water content of the soil at wilting point

^C REW - When the soil is at its peak water content, this is the amount of readily evaporable water

^D TEW - When the soil is at its peak water content, this is the amount of total evaporable water

^E Ze - Depth of surface soil layer that is subject to drying by way of evaporation.

Table 3-2. FAO - 56 parameters selected by the authors to determine the average evaporation reduction coefficient (Kr) for loam, silty clay loam, and clay soils.

	Chosen θ_{FC}^A to Obtain Avg Avail. Water ^B (m ³ Soil Water /m ³ Soil)	Chosen θ_{WP}^C to Obtain Avg Avail. Water ^B (m ³ /m ³)	FAO - 56 Avg. Plant Available Water $\theta_{FC} - \theta_{WP}$ (m ³ /m ³)	Avg. FAO - 56 REW ^D (mm)	Computed TEW ^E (Ze=0.1m) ^F (mm)	Computed TEW $\theta_{FC} - 0.5\theta_{WP}^G$ (m ³ /m ³)	Final Water Content $\theta_{FC} - \text{TEW}$ (m ³ /m ³)
Loam	0.263	0.108	0.155	9.0	20.9	0.209	0.054
Silty Clay Loam	0.350	0.195	0.155	9.5	25.3	0.253	0.098
Clay	0.375	0.215	0.160	10.0	26.8	0.268	0.108

^A θ_{FC} is the volumetric water content of the soil at field capacity

^B ITRC chosen θ_{FC} and θ_{WP} were as near to their mean value as possible while still yielding the average possible FAO - 56 available water for the given soil type

^C θ_{WP} is the volumetric water content of the soil at wilting point

^D REW - When the soil is at its peak water content, this is the depth of readily evaporable water

^E TEW - When the soil is at its peak water content, this is the depth of total evaporable water

^F Ze - Depth of surface soil layer that is subject to drying by way of evaporation

^G FAO - 56 assumes the TEW for a soil has been depleted when the volumetric soil water content is reduced to half of the θ_{WP} for the soil.

Figures 3-3, 3-4, and 3-5 illustrate the Kr relationships that were measured (squares and diamonds) by Chanzy and Bruckler (1993) and the average relationships as defined by the authors ("ITRC") using FAO - 56 (circles and triangles) for the three soil types. The data point in the middle of the ITRC-defined average falling-rate-stage of each Kr relationship is the wilting point of the soil.

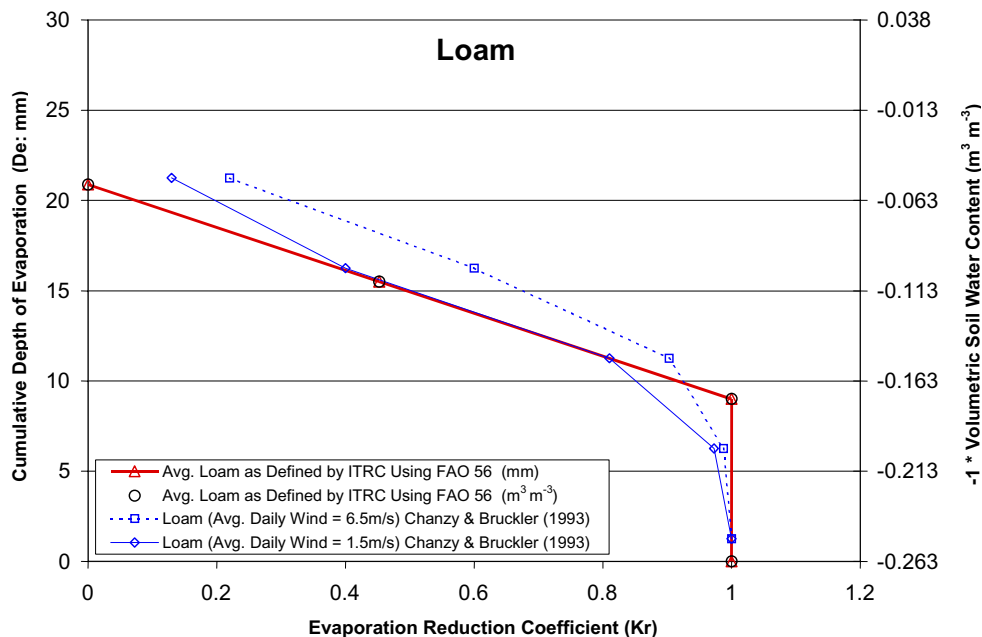


Figure 3-3. Comparison of the measured loam (Avignon, France) K_r relationships derived from Chanzy and Bruckler (1993), against the K_r relationship of an average loam soil using FAO - 56.

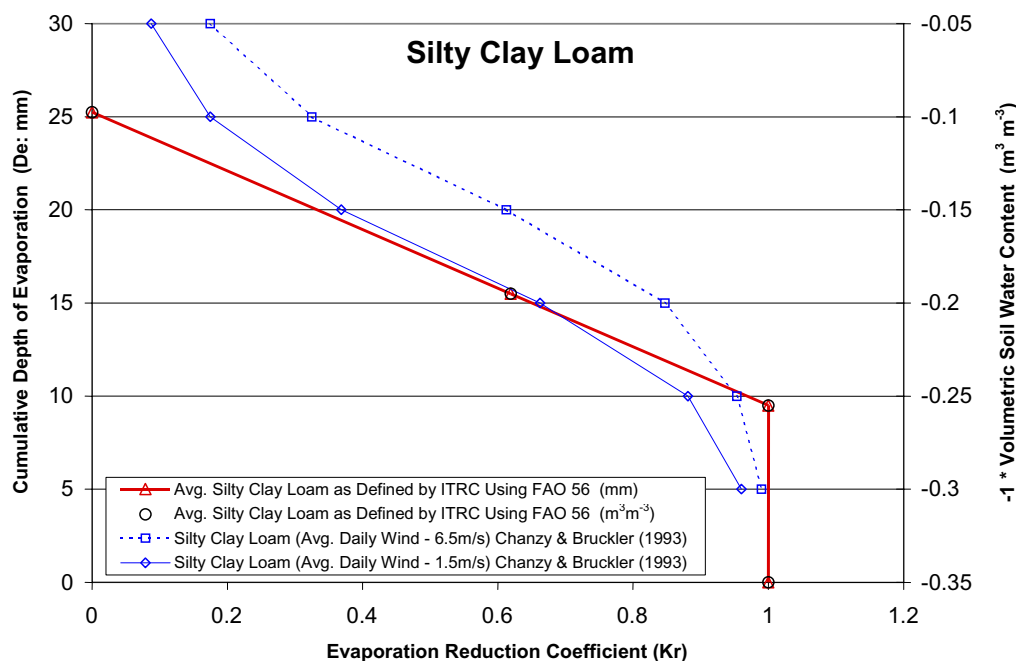


Figure 3-4. Comparison of the measured silty clay loam (Avignon, France) K_r relationships derived from Chanzy and Bruckler (1993), against the K_r relationship of an average silty clay loam using FAO - 56.

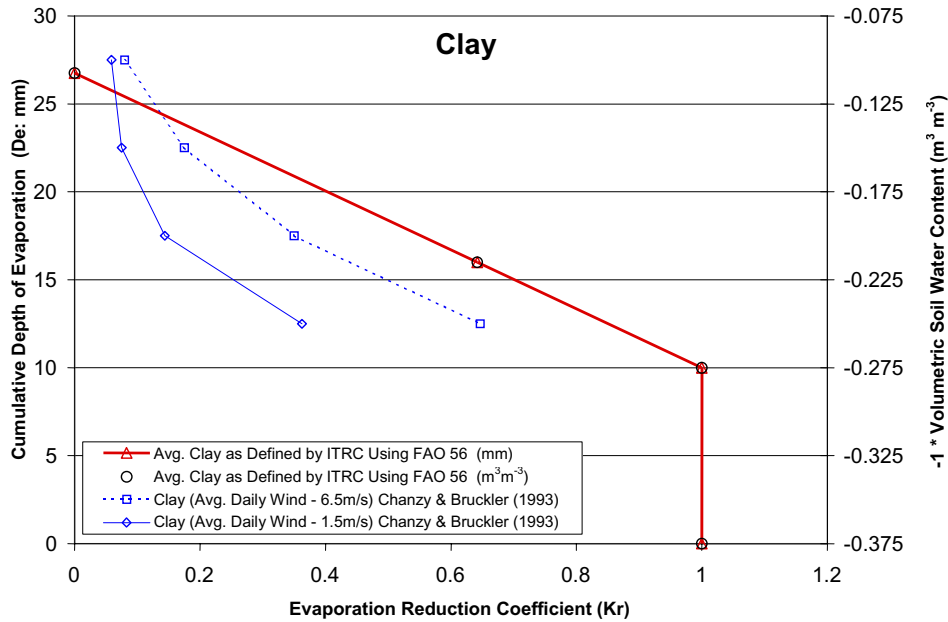


Figure 3-5. Comparison of the measured clay (Avignon, France) Kr relationships derived from Chanzy and Bruckler (1993), against the Kr relationship of an average clay using FAO - 56.

The key points from this section are:

1. For all 3 soil types, the measured (Chanzy and Bruckler, 1993) Kr relationships had nearly identical falling rates.
2. For all 3 soil types, the average Kr relationships from FAO - 56 had similar falling rates to the measured rates.
3. The average Kr relationships from FAO - 56 are shifted relative to the measured Kr relationships, particularly for the clay. This is an indication that the readily evaporable water (REW) for the Avignon, France soils was somewhat different from the average FAO - 56 REW values for that soil.
4. Considering that the FAO - 56 computation was done without knowing the soil properties for the 3 soil types presented in Chanzy and Bruckler (1993), the measured and average Kr relationships using FAO - 56 are fairly close.
5. "Average" FAO - 56 soil textures used to define the Kr relationship will give reasonably accurate results.
6. FAO - 56 suggests that the depth of the surface soil layer that is subject to evaporation (Ze) may be around 0.1 to 0.15 m. Following this, the average Kr relationships for the soils were defined by the authors using a Ze of 0.1m. It is interesting to note that the average Kr relationships for the three soils are similar to the measured relationships even though the measured evaporation by Chanzy and Bruckler was determined by evaluating only the top 0.05m of soil.

1.2.1.3 FAO - 56 Modifications

Allen et al (1998) presented the FAO Penman-Monteith equation and crop coefficient procedure that computes both the E and T components of crop ET. The soil evaporation computations used the relationship described in the previous section. For this study of evaporation on California's irrigated lands, several modifications were made to the FAO - 56 procedures. They were:

1. Partitioning the evaporation into precipitation and irrigation origins. Evaporation on the day of a precipitation event, and the days following that event, was designated as evaporation from precipitation until the available precipitation water was used.
2. The initial basal crop coefficient (K_{cb}) represents evaporation. Initial K_{cb} values range from 0.15 – 0.35. As a plant emerges or blooms, the evaporation portion of K_{cb} declines. The partitioning procedure between evaporation and transpiration for the initial K_{cb} is described in section B-1.2 of Appendix B.
3. Evaporation from wet plant surfaces was computed for 2 days per sprinkler application. This is because most sprinklers in California are hand move sprinklers, which typically wet one area for 2 days. The evaporation for those 2 days was set as the difference in E_{To} between a stomatal resistance of 0 s/m and 70 s/m.
4. A 3rd stage of evaporation was included, to account for evaporation from open cracks on cracking clay soils and reduced vapor diffusion on some silt loam soils.

1.2.1.4 Comparison of FAO-56 ET Against Measured ET from Multiple Sources

The FAO - 56 simulated evaporation was compared against measured evaporation for 6 lysimeter and 1 Bowen Ratio measured bare or near bare soil evaporation data sets. Detailed information about each data set is found in Appendix E. Three of the lysimeter data sets are from Bushland, TX (Howell et al., 1995), one is from Davis, CA (Parlange et al., 1992), one is from Temple, TX (Ritchie, 1972), and one is from Kimberly, ID (Wright, 2001 pers. comm.). The Bowen Ratio data set was from Farahani and Bausch (1995). These data sets were selected because they appeared to have been collected with excellent quality controls.

Another FAO - 56 simulation was run to compare data from Farahani and Bausch (1995) that used 12-hour measurements with Bowen Ratio equipment as an estimate of the daily evaporation. The FAO - 56 simulation results matched those of the 5 lysimeter studies more closely than they did those of the Bowen Ratio study. In the absence of other extended period evaporation measurements that used Bowen Ratio equipment to compare against, the Farahani and Bausch (1995) data are listed but not included in Table 3-3 with the averages for the lysimeter studies.

Table 3-3. Comparison of FAO - 56 simulated evaporation against various field measurements of evaporation.

	Ritchie, 1972	Parlange et al., 1992	Howell et al., 1995	Howell et al., 1995	Howell et al., 1995	Farahani & Bausch, 1995
Year measurements were collected	1969	1990	1989	1991	1992	1993
Measurement method	Lysimeter	Lysimeter	Lysimeter	Lysimeter	Lysimeter	Bowen Ratio Equipment
# of days from start to end of the evaluated period	12	10	31	41	40	25
Rain or irrigation during the period (mm)	48.4	18.1	74.0	104.8	95.7	56.1
Measured cumulative bare soil evaporation (mm)	24.2	16.8	52.8	93.7	81.2	60.3
FAO - 56 modeled cumulative bare soil evaporation (mm)	24.7	18.3	51.5	87.9	84.4	47.1
Absolute value of the % difference between measured and FAO - 56 modeled cumulative E	2.1%	8.9%	2.4%	6.1%	3.9%	21.9%
Ratio of mean daily FAO - 56 modeled E/ETo to mean daily measured E/ETo	1.03	0.84	0.85	1.11	1.06	0.85
Avg. % difference between lysimeter E value versus FAO - 56 modeled cumulative E.						4.7%
Avg. of lysimeter experiment ratios of mean daily FAO - 56 Modeled E/ETo to mean daily measured E/ETo						0.98

The E/ETo values estimated with the FAO - 56 procedure closely tracked the measured values (Figure 3-6), with a tendency to have either similar or a more pronounced response to large precipitation or irrigation events and to have a smoother and smaller response to smaller events. An example of corresponding FAO - 56 simulated and measured cumulative evaporation for experiments is displayed in Figure 3-7. The average ratio of the mean daily-modeled E/ETo to the mean daily measured E/ETo was 0.98 for the 5 lysimeter experiments. The average absolute value of the percent difference between the measured and the FAO - 56 modeled cumulative evaporation for these experiments was 4.7% (Table 3-3).

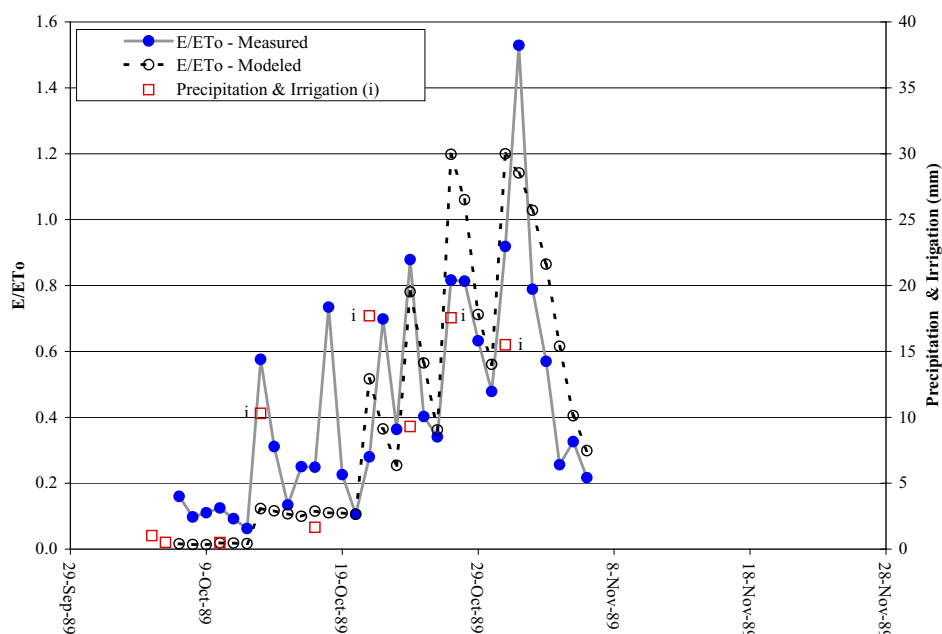


Figure 3-6. Comparison of bare soil E/ETo ratios. Lysimeter measured (in 1989 at Bushland, TX - Pullman Clay Loam – reported by Howell et al., 1995) and FAO - 56 model results.

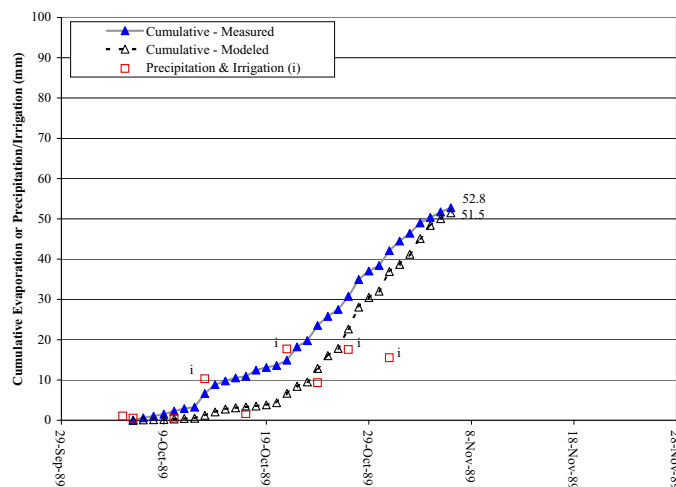


Figure 3-7. Comparison of bare soil cumulative evaporation. Lysimeter measured (in 1989 at Bushland, TX - Pullman clay loam - reported by Howell et al., 1995) and FAO - 56 model results.

1.2.2 Soil Evaporation with Drip Irrigation

Discussions with irrigation dealers and farmers almost always bring out their opinion that evaporation is considerably less with drip irrigation than with other irrigation methods. Conversations with and a search of publications by academics and researchers, however, gave less credence to the notion of reduced soil evaporation on typical drip/micro systems.

1.2.2.1 Interviews and Observations

Kincaid (2000) noted that in USDA/ARS Idaho field comparisons between sprinkler and drip irrigation he was not able to measure daily differences in evaporation between the methods. However, the ET (scheduling) model he uses estimates that for a bare soil condition the difference in surface evaporation between surface drip (or furrow) with partial wetting and sprinkler with full wetting could be as much as 50 percent of the potential ET for the first day after an irrigation, or until the surface is visually dry. As the crop approaches full cover this difference is reduced to probably less than 5 percent. On an overall seasonal basis, Kincaid estimated that overall water use efficiency when using surface drip, vs. center pivot or linear move, is increased by 5 to 10 percent.

Hsiao of UC Davis (T. Hsiao, 2000) is conducting research to identify potential savings in soil evaporation (E) by using surface drip as opposed to furrow. He notes that drip can reduce evaporation under two conditions:

1. When the crop or tree canopy cover is less than 100%
2. When the soil is light textured with a low water holding capacity. When the texture is light (i.e., sandy), the required time between furrow irrigations is sometimes reduced to 5 days, resulting in more opportunity for soil evaporation to occur.

The second point can be explained by the logic that under complete crop cover or when there is a good heavy soil, soil evaporation from surface drip is similar to that under furrow irrigation. This is because, although the drip wets a smaller area, that area is wet for much of the growing season, whereas with furrow irrigation, more of the surface area is wetted, but it dries, reducing the amount of soil evaporation.

1.2.2.2 Literature on Soil Evaporation with Drip Irrigation

12221 Subsurface drip (SDI)

Burt et al. (1997) noted that crop ET (ET_c) will be less for a well-watered crop with dry soil and plant surfaces (as can be the case with SDI) than if the crop were irrigated with a method that wets the soil and plant surfaces. Further, the method that wets the soil surface can also result in more weed development and loss of applied water through weed transpiration. Evett et al. (1995b) identified that for treatments with similar canopy development, there is no difference in seasonal ET of drip irrigation and furrow irrigation. Evett et al. (1995b) hypothesized that improved yields for subsurface systems are most likely due to more water being available to the plants irrigated with those systems since, relative to surface drip, less of the applied water is lost to evaporation.

Using field measurements, Evett et al. (2000) compared surface and subsurface drip irrigation treatments for a corn-growing season in Bushland, TX, using the coupled mechanistic water and energy balance model ENWATBAL. The treatments evaluated were surface and 0.15 and 0.30m depth SDI. Daily irrigation was scheduled to replace crop water use as measured with neutron probe. Modeled transpiration was nearly identical for the three irrigation methods (about 430mm over 114 days following emergence), but soil evaporation for the two SDI treatments were 51 and 81 mm less respectively than the surface treatment. The higher soil evaporation for the surface treatment was reported to have occurred during the partial cover period. From their work, Evett et al. (2001) estimated that water savings of up to 10% of seasonal precipitation and irrigation could be achieved using 0.3m deep SDI emitters. Blaine Hanson of the UC Davis Dept. of LAWR indicates similar data and thoughts with processing tomato research near Five Points, CA (Blaine Hanson, personal communication, Feb. 2001).

Ayars et al. (1999) reviewed 15 years of research from the USDA-ARS Water Management Research Laboratory, Fresno, CA. Cited is Phene et al. (1987), who reported that with SDI, E was minimal, while T increased. The high T with the SDI systems was postulated to improve evaporative cooling of the crop canopy, and to increase stomatal opening and photosynthesis. Evaporation from winter rains and from pre-irrigations by sprinkler or furrows, and evaporation from a wet seedbed for establishing a plant stand were not discussed.

The trend among California's growers of lettuce, broccoli, cauliflower, peppers, and other similar crops is to move away from SDI and to surface retrievable drip systems because of the inherent difficulties in managing SDI in many situations. Management problems and surface wetting with SDI on orchards have been frequently observed (Burt and Styles, 1999).

12222 Surfacedrip/micro

Dasberg (1995) found that sprinkler irrigations and micro irrigation that resulted in similar soil surface wetting resulted in similar amounts of the soil evaporation component of ET.

Burt and Styles (1999) and Burt (2000) note that some types of drip/micro system conditions will create at least as much, and probably more, soil evaporation than will occur under furrow irrigation. The vast majority of drip/micro systems are above ground, and the wetted areas may be quite large with some crops and emitter designs. Those wet soil surface regions are almost continuously wet, contributing to a high soil evaporation loss. This was also noted by Bresler (1975) and Meshkat (2000). For about 15 years, Westlands Water District in the central San Joaquin Valley of California has collected district data which indicates 10 – 15% higher ET, part of which is E, for drip on almonds, as opposed to other irrigation methods (Westlands Water District Water Management Plan, 1993).

Simulations using the FAO - 56 method for this evaporation study showed that the evaporation losses under drip/micro can be considerable, and depend upon the type of drip/micro system used, the soil type, and the percent soil surface wetted area. Some of the simulated results are shown in Figure 3-9.

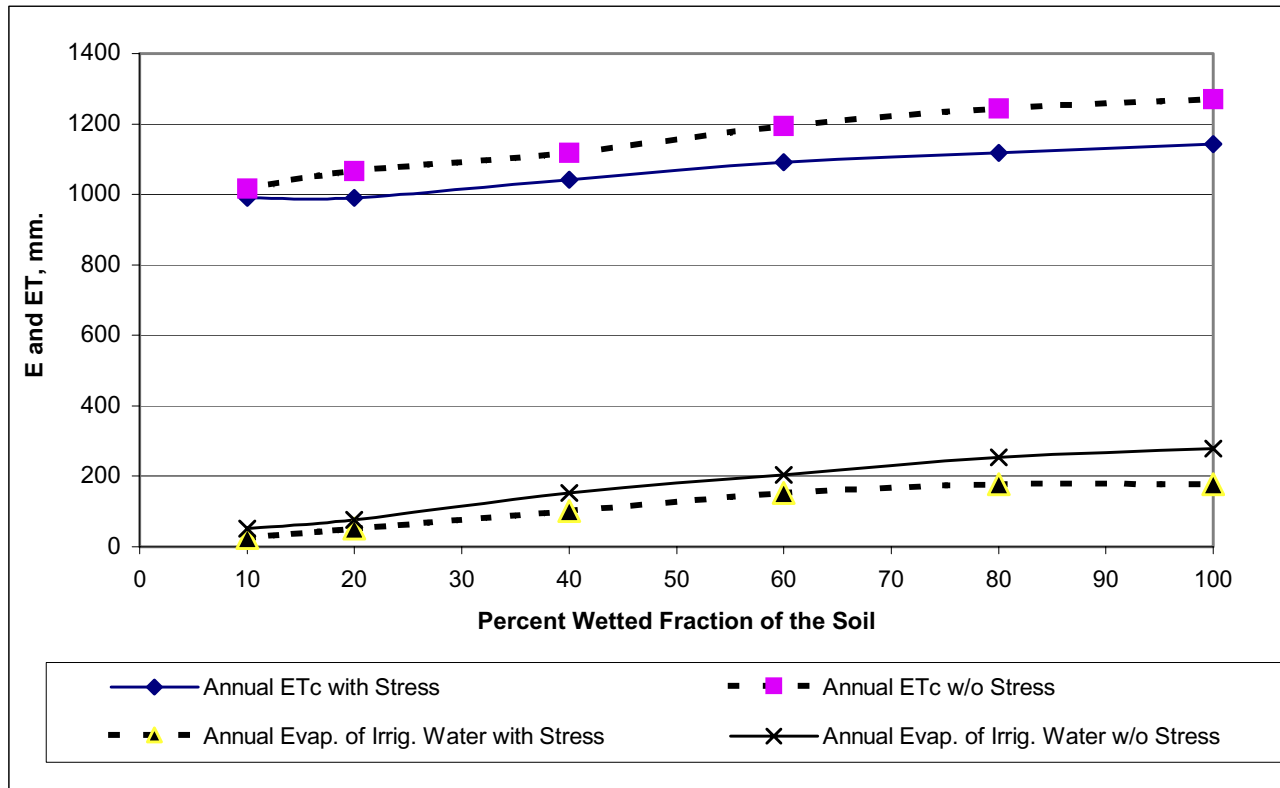


Figure 3-9. Crop evapotranspiration and evaporation as the fraction of wetted area. Stressed and non-stressed almond trees irrigated with drip or microsprayers on the western side of the San Joaquin Valley of California. Other than crop stress and soil wetted fraction, the same crop parameters used in the overall study were used to do this comparison. Adjustments for bare spots and decreased vigor were not taken into account.

Recommendations

1. This report provides statewide estimates of annual Transpiration and Evaporation from precipitation and irrigation. Only part of the Evaporation may be conservable. An economic analysis of the conservation potential of various measures should be developed. For example, the total average annual evaporation from irrigation is estimated to be approximately 2.7". An investment in SDI, which might cost \$1,000/acre, might save half of this water. The estimated cost/AF conserved should be compared with other available conservation options.

2. The majority of annual evaporation (4.7 million AF/year, or 69% of the total evaporation) is from precipitation. This implies that research on rainfall precipitation conservation merits further funding. This type of research has typically been conducted in the Midwestern states where the majority of land was not irrigated. It is clear from the literature review that mulches, for example, can help to conserve winter moisture. More research on crop stubble and soil mulches is warranted.
3. It is apparent that within a field, certain practices will result in higher or lower evaporation within that field. It is also apparent that within that field, an increase in evaporation will result in a lower transpiration if there is a growing crop. The tradeoff is not equal – the increase in evaporation is typically greater than the reduction in transpiration. However, what is not known is how the tradeoff extends beyond the boundaries of a field. For example, an increase in evaporation in one field may increase the relative humidity of the air, and therefore reduce the ET in downwind fields. If this tradeoff is substantial, local field evaporation suppression efforts may only have a 40% or 60%, for example, net impact on the water balance in a region. Further research could approach this problem both with localized remote sensing and also theoretically based on the apparent local rise in relative humidity.
4. The issue may not be so much one of reducing evaporation and transpiration, as it is one of increasing crop yield per unit of ET. Therefore, research, demonstration projects, and information dissemination on related topics, such as optimizing fertigation practices, is of high priority.
5. State and Federal programs that either report ET or require the reporting of ET should be consistent on the following:
 - a. The crop ET for water balances should be de-rated (by 10% as a rough starting approximation) to account for bare spots and lack of vigor throughout fields. This is in contrast to ET values to be used for irrigation scheduling. Both sets of values are provided on ITRC's web page <http://www.itrc.org/ETWeb/WBAndISHomePage.htm>
 - b. ET values for irrigation district water balances should be for a year, not just for a crop season.

6. The California DWR CIMIS program should initiate a new type of quality control program which performs a quality control check on the historical solar radiation (R_s) and relative humidity values for each weather station. Erroneous data should be replaced or flagged. Such a program does not presently exist, and therefore every individual research project must perform its own quality control check on historical data. In most likelihood, most users of the data are not aware that there may be data problems because the CIMIS program does insert flags on other types of problems. The present method of flagging obvious errors does not catch systematic instrumentation errors (of the type examined in this report) with solar radiation (the single most important value for ETo computations) or relative humidity.